TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

FOUNDED IN LONDON 1909 : INCORPORATED 1930

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VOLUME II—No. 2
FEBRUARY 1937

32 VICTORIA STREET
LONDON SW1

NOTES ON RECENT MEETINGS AND EVENTS

General Meeting in London.

A meeting of the Society was held in the Lecture Theatre of the Institution of Mechanical Engineers, Westminster, S.W.1, on Tuesday, January 12. The chair was taken by the President at 7 p.m.

The minutes of the last meeting having been taken as read, the names of applicants for membership were presented in the usual way.

The President then called upon Mr. J. W. Howell to present his paper entitled "Some Important Considerations in Colliery Lighting" which was illustrated by demonstrations and exhibits. On the motion of the President, a cordial vote of thanks was passed to Mr. J. W. Howell for his paper and to the firms who had arranged exhibits.

An interesting discussion followed, in which the following took part:—Mr. F. H. Wynne (Mines Department), Mr. G. M. Harvey (Mines Department), Mr. E. A. Hailwood, Mr. C. A. Morton, Mr. J. E. Lane, Mr. Howard Long, Mr. H. G. Batson, Mr. Cecil Hughes, and Mr. J. S. Dow (summarising written contributions).

Mr. Howell briefly replied to the discussion, and the meeting then terminated.

Forthcoming Events

Feb. 9th. Mr. H. C. Weston on **Lighting and Industrial Performance.** *(Meeting of the Industrial Lighting Section of the Illuminating Engineering Society at Watson House, Townmead Road, Fulham, S.W.6);* **6.0 p.m.**

Feb. 12th. Informal Social Evening of the Illuminating Engineering Society *(at St. Ermin's Hotel, St. James's Park, S.W.1);* **6.30 p.m. Tickets 2/6 each.**

Feb. 17th. Mr. G. H. Wilson on **Road Lighting and Road Surfaces.** *(Meeting of the Institution of Civil Engineers (Manchester District) at 36, George Street, Manchester);* **6.0 p.m.**

Feb. 18th. Mr. P. Freedman on **Low Voltage Neon.*** *(Local Sectional Meeting of the Illuminating Engineering Society at Cadora Restaurant, Union Street, Glasgow);* **7.30 p.m.**

Feb. 22nd. Mr. G. T. Winch on **Some Practical Aspects of Precision Photometry.** *(Meeting of the Photometric Section of the Illuminating Engineering Society at the Research Laboratories of the General Electric Company, Ltd., Wembley);* **6.0 p.m.**

Feb. 23rd. Mr. Howard Long on **Diffusion and Shadows.** *(General Meeting of the Illuminating Engineering Society at the E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, London, W.C.2);* **6.30 p.m.**

March 9th. Two papers reviewing **Street Lighting Problems** by Dr. S. English and Mr. R. Maxted *(General Meeting of the Illuminating Engineering Society in the Lecture Theatre of the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W.1.);* **6.30 p.m.**

March 16th. Annual Dinner of the Illuminating Engineering Society *(at the Trocadero Restaurant, Piccadilly, London, W.1);* **6.45 p.m.** for **7.30 p.m.**

**Repetition of paper read in London on December 8th, 1936.*

Applications for Membership.

At the general meeting of the Society held on January 12, the names of the following applicants for membership were presented:—

Elections Pending.

Corporate Members:—

Hale, F. M. .....51, Grafton Road, New Malden, Surrey.

Hallam, E. C. .....52, Great Malborough Street, London, W.1.

Hopkinson, R. G. ....The Research Laboratories of the General Electric Co., Ltd., Wembley, Middlesex.

Hoskins, C. A. .....1, Uplands Way, Grange Park, Winchmore Hill, London, N.21.

Lambert, G. E. V. ...31, Idminston Gardens, Worcester Park, Surrey.

Lane, J. E. .....36, Ridge Road, Winchmore Hill, London, N.21.

Latreille, A. J. .....46, Parkwood Road, Isleworth, Middlesex.

Meacock, H. F. .....59, High Street, Hampton, Middlesex.

Youatt, D. .....Winfield, East Horsley, Surrey.

Country and Foreign Members:—

Burland, W. J. .....16, Lilybank Avenue, Muirhead, Chryston.

Inglis, L. W. .....50, Wellington Street, Glasgow.

Kelly, T. S. .....20, East 57th Street, New York, U.S.A.

Walton, J. R. .....May House, 15, Longford Road, Longford, Stoke-on-Trent.

Elections Completed.

At this meeting the names of those announced on December 8, which were published in the issue of the Transactions (Vol. II, No. 1, p. 2, January, 1937) were read again, and these applicants were formally declared members of the Society.

BINDING CASES FOR TRANSACTIONS.

A new supply of Binding Cases for Transactions is now available, and will be supplied to Members at the cost of 2/6 each, post free (price to outsiders 3/6 each, post free). In order to save cost of postage and labour, Members are requested to call at 32, Victoria Street, London, S.W.1, for their binding cases or to arrange to receive them at the General Meetings.

LOW VOLTAGE NEON

by PAUL FREEDMAN, B.Sc., A.M.I.E.E.

(Paper read on Tuesday, December 8th, 1936.)

INTRODUCTION.

The present paper is concerned with developments in connection with discharge tubes employed for luminous signs and decorations. In the industry such discharge tubes are commonly described as "neon," a somewhat loose description, since, although most of these are neon filled, a considerable number contain argon or helium, or mercury vapour together with permanent gases. Ordinary "neon" tubes at present in general use are positive column discharge tubes requiring for their operation from 500 to 3,500 volts per section, the sections being grouped whenever possible so that the voltage for each group of several sections is about 10,000 volts. These high voltages necessitate special precautions which are stipulated by the electric supply companies and by municipal authorities. Special transformers, high tension cable, a fireman's switch, and, in the case of a D C. supply, a rotary convertor or similar machine, are essential. Great care must be taken in the matter of insulation and proper earthing; steps must be taken against generation of high frequency oscillations, and condensers must be employed to improve the power factor of the installations. The above features have made it essential for manufacturers to give nearly every customer individual attention with regard to design and erection of his installation and to provide maintenance service. Consequently, distribution of high tension neon through wholesale and retail distributors is an impossibility; there is no standardisation as regard shapes and sizes of neon letters and decorations, or length of tube sections, and the industry has been unable so far to achieve a mass-production basis.

This has made it most desirable to produce a low-voltage type of neon which could be operated direct off the normal household electric supply, could be installed, interchanged, and replaced as easily as ordinary incandescent lamps, would be simple in construction, automatic in operation and would require no attention, would be capable of standardisation. could be distributed through wholesale and retail agencies, and would make it possible for the industry to organise on mass-production lines.

Basic Requirements.

Before proceeding to the description of the various type of low-voltage neon developed and in the course of development, it is desirable to consider the requirements which must be fulfilled by any type of low-voltage neon which could be regarded as satisfactory both by the manufacturer and by the consumer.

The first consideration is that the low-voltage neon should be operable both on A.C. and on D.C. supplies ranging from 200-250 volts and from 100-150 volts, and that, above all, it should be satisfactory at preponderant supply voltages. In this country the overwhelming majority of domestic electric supplies are 200 to 250 volts, 50 cycle A.C., most of these being 230-volt. supplies, and it is essential that the low-voltage neon in this country should give a satisfactory performance at these voltages.

The second consideration is simplicity of construction and operation, and the minimum, preferably the total absence, of auxiliary devices. Simplicity of construction and operation are the prerequisites of low initial cost, aid standardisation, minimise chances of premature failure, and are important factors towards elimination of maintenance service and organisation of wholesale and retail distribution. Auxiliary devices are undesirable, since, apart from increase in cost, they tend to reintroduce in other forms the factors which, in the case of high-tension neon, have made it necessary to treat each customer as an individual problem of installation and maintenance.

The third consideration is that the dimensions of low-voltage neon tubes should be in accordance with the established requirements of the industry. The prevailing demand is for tubes 10-11 mm., 15-16 mm., and 20-22 mm. diameter. There are very few installations in less than 8 mm. or more than 30 mm. tubing. Sections are usually 1 to 2.5 metres long, but section lengths from 15 cm. to 6 metres are produced. It is therefore essential that low-voltage neon tubes could be produced in any length from 15 cm. to 6 metres and in the prevailing diameters. It is also essential that such low-voltage neon tubes could be bent in any desired manner.

The fourth consideration is energy consumption. From the customer's point of view, tube efficiency is relatively unimportant, the primary consideration being the general appearance of the sign and the total energy consumption, while from the manufacturer's point of view it is important that the tubes should have a satisfactory, but not an excessively long life. Hence the prevailing practice is to operate neon at loadings which do not always

correspond to optimum luminous efficiency. Taking the high-tension neon figures as a basis, low-voltage neon should be designed to operate at not more than 5 watts/ft., 7 watts/ft., and 9 watts/ft. for 10-11 mm., 15-16 mm., and 20-22 mm. diameter tubing respectively.

The fifth consideration is the power factor on A.C. circuits, assuming the majority of supplies are A.C., as is the case in this country. The electric supply companies stipulate that the load power factor should not be less than 0.8. In the case of high-tension neon the uncorrected over-all power factor, according to Schallreuter, is generally 0.4 to 0.5, and according to McMillan and Starr (1) may be as low as 0.25, but there is no *a priori* reason why a gaseous discharge tube should have a low-power factor; in the case of the high pressure mercury vapour lamp, for example, the power factor for the lamp alone is about 0.9. It is not absolutely essential that the low-voltage neon should have a high-power factor, since a low-power factor could be improved, as in the case of high-tension neon, by means of condensers, but the use of condensers would be highly undesirable since the capacity employed would be dependent upon the diameter and length of tubing, the specific gas filling, and the supply voltage, and would therefore complicate the installation problem.

The sixth condition is the absence of high frequency oscillations. While such high frequency oscillations can be legislated for by means of high frequency chokes, it would be better to avoid all possibility of radio interference by employing a type of discharge tube whose characteristics do not favour the generation of high frequency oscillations. This condition would be satisfied by a tube whose current wave would have a very small percentage of harmonics, that is to say, a discharge tube with a high-power factor.

The seventh condition is satisfactory colour and appearance. The present requirements of the public are principally for red-orange of pure neon. About 80 per cent. of tubes now employed are red-orange, about 10 per cent. blue, about 5 per cent. green, and the remaining 5 per cent. yellow, white, and other colours. The above proportions are slowly changing, the percentage of red-orange diminishing in favour of other colours, particularly blue and green. It is therefore desirable that low-voltage neon could be produced in all colours, and essential that it should give absolutely satisfactory results in red-orange. Nearly all neon lighting at present employed presents, when the tubes are in good condition, a steady, uniform luminosity. The only exceptions to this are the "on and off" signs, writing neon, and ripple tubes employed for shop window display. It must not be concluded, however, that the public would not tolerate any appearance other than that to which it is accustomed. There is a definite indication that any animated appearance would be appreciated provided the light variations are rhythmic, arresting, and pleasing, but not tiring to the eye. In fact it can be said that the public is prepared to accept any appearance that is consistently pleasing, provided the tubes are of the right brilliance and colour.

The eighth condition is luminosity. In the case of lamps employed either for ordinary ilumination or for projection purposes, performance is defined in terms of candle-power and candle-power per watt. In the case of discharge tubes employed as signs or decorations, however, conditions are entirely different. The illumination furnished by such tubes is of no interest whatever. What is required is that the tubes should appear arrestingly bright to an observer's eye from likely points of observation, without a sensation of glare being produced, and that such brightness should be both adequate *per se* and in comparison with other luminous signs and decorations which may be viewed simultaneously or within a short time interval. This accounts for the fact that information regarding the candle-power of neon signs and decorations is neither requested by the public nor offered by the manufacturers. In estimating the luminosity of neon signs or decorations and in comparing such luminosity with that of other signs or decorations, the observer bases his judgment entirely on his visual sensations, using his eye as a measuring instrument. The human eye is not adapted to act as a light intensity meter: it is capable of judging presence or absence of equality of illumination but not adapted to estimate the magnitude of differences; nevertheless, judgment by eye is the only thing that counts. Luminosity of a neon sign or decoration as judged by an observer viewing the installation could not be expressed quantitively by the corresponding tube candle-power or candle-power per unit area of projected tube surface, since these quantities would not be proportional to the effect produced. Some form of quantitive expression of the effect upon the observer is, nevertheless, most desirable. The author, in a recent article (2), proposed that tubes should be rated in terms of visual sensation which, according to Weber-Fechner law, is proportional to the logarithm of candle-power. While such a rating makes no allowance for the effect of tube diameter, colour, and the nature of the background, it is more in accordance with the magnitude of the effect produced upon the observer than forms of rating which have been proposed. Apart from the question of the terms in which luminosity should be expressed, there is the equally important question as to what luminosity is actually desirable. It has been stated that luminosity should be such as to exert a maximum attraction without creating the sensation of glare. This is only broadly true. It is absolutely true as far

as outdoor signs and decorations are concerned, and the light intensities of various tubes at present employed are in accordance with the public's requirements. It is not true of shop window displays where conditions are much more complicated. One object of a neon shop display is to attract the public to the window, and from this point of view the conditions are the same as for outdoor signs and decorations. When the potential customer has approached the window, however, the problem becomes quite different; it then becomes desirable that the neon display should neither weary the observer nor distract his attention from the goods displayed, but act as a pleasant and not too obtrusive decoration. This aspect has been considered by the author (2), and he has pointed out that for a given field brightness the brightness of a luminous body situated in the field corresponding to a pleasant sensation is 5.75 per cent. of the brightness of that body corresponding to a perceptibly uncomfortable sensation. In other words the ideal brightness of a shop window neon display, viewed at close quarters, is less than 6 per cent. of the ideal brightness of the same neon display viewed at a distance, assuming field brightness at close quarters and at a distance to be identical. Further consideration shows even greater difference of requirements. The illumination of a well-lighted shop window may vary between 7 foot-candles for a small shop to 20 foot-candles for a large shop, which is much greater than the illumination of the corresponding building exterior; on the other hand the reflecting power of the goods displayed may vary from about 84 per cent. for pure white down to about 6 per cent. for crimson (3). Thus, while at a distance the well-illuminated shop window requires a neon display brighter than an outdoor sign, the average reflecting power of the goods makes it desirable from point of view of effect at close quarters that the brightness of the neon display be only 2.5 per cent. of the value desirable for the effect at a distance. The present practice is to employ for shop window display neon tubes whose brightness does not appear to vary with distance and is the same as that of outdoor signs and decorations. This is by no means an ideal solution of the problem. There is an indication that it should be possible to produce neon which would appear to an observer to be much brighter at a distance than at close quarters; this effect has been obtained by the author in low voltage neon tubes constructed by him and described later in this paper, and it appears that a similar effect can be produced with any type of discharge tube by employing a glass envelope with suitable longitudinal ridges.

The ninth condition is life. High-tension neon tubes often last 5,000 to 6,000 hours, and have been known to last as long as 10,000 hours. Experience has shown, however, that it is unwise to give a guarantee of life for more than 2,000 to 3,000 hours. There is no reason to suppose that the public would require a longer life for low voltage neon; on the contrary, the circumstance that replacements could be made as easily as in the case of ordinary incandescent electric lamps would probably induce the public to accept a somewhat shorter guaranteed life. As far as manufacturers are concerned, tube life beyond that required by the public would be an obvious disadvantage.

Investigations concerning the problem of low-voltage neon may be divided broadly into three classes:

(a) Discharge tubes operated by high frequency current derived from mains operating high frequency units.

(b) Positive column discharge tubes operating at household supply voltages, possessing hot cathodes of high electron emissivity, starting means, and auxiliary means of ionisation of the positive column region.

(c) Negative glow discharge tubes operating at household supply voltages.

High Frequency Neon.

Of these three the first is the oldest. High frequency discharges through gases have been investigated by E. Wiedemann and Ebert in 1893 (4), and by Himstedt in 1894 (5), and attempts to apply high frequency currents to neon tube lighting were made by Moore-Licht Akt. Ges. in 1912 (6). Although high frequency neon is often described in the industry by those associated with it as "low-voltage neon," such description is hardly appropriate, since high frequency neon actually operates at high voltages. It appears that the name "low-voltage neon" was originally applied to high frequency neon for reasons of sales policy, the absence of electric shock characteristic of high frequency currents being associated in the public's mind with "safe," low-voltage sources of electricity such as car accumulators and electric bell batteries. In 1912 Moore-Licht Akt. Ges. (6) produced discharge tubes with external electrodes, containing helium, neon, or mercury vapour with addition of permanent gas, and operated by high frequency current supplied by a tesla transformer or an oscillating circuit with one or more spark gaps. It appears that a satisfactory clean up of deleterious gases was never obtained in these tubes, probably owing to absence of internal electrodes; the colour of neon filled tubes, for example, was never red-orange, but always pink. In 1923 E. V. Hayes-Gratze (7) produced electrodeless discharge tubes situated between two conductors, one of which was earthed and the other connected to the free end of a high frequency coil. He employed both spark gap and oscillator valve sources of high frequency current. He also produced electrodeless discharge tubes energised by means of conductors situated behind and out of contact with the tubes, and obtained a travelling neon effect by means of metallic conductors connected to the high frequency source and mounted on a moving band. He experienced a difficulty in eliminating stray high frequency discharges, and in 1924 sought to overcome this by employing discharge tubes of the usual positive column type, with internal electrodes connected across the terminals of a secondary winding of an oscillator. D. P. A. A. Kayser further explored the possibilities of writing neon in 1927 (8), producing stationary and moving luminous bead effects by means of adjustable oscillators. Subsequent investigations have been chiefly devoted to development of

suitable valve oscillator circuits, means of preventing stray high frequency discharges, and electrostatic screening for prevention of radio interference. In 1929, however, some beautiful effects were obtained by J. C. Wilson (9), who produced luminous, intertwined helical streamers within a positive column discharge tube by means of high frequency current; and in 1931 G. C. Adams (10) developed a variable frequency circuit in which the luminosity of the discharge was varied by cyclic variations of frequency of the high frequency supply. Various difficulties have been encountered in the course of development of high frequency neon. In the first place, high frequency currents are difficult to insulate, even in a dry warm room, and much more so outdoors, where the installation may be subject to damp, fog, rain, or snow. There is, of course, no danger of electric shock, but the minute high frequency spark and brush discharges are obviously objectionable. In the second place, high frequency neon is prone to act as a source of serious radio interference unless proper care is taken to obtain adequate electrostatic screening. Radio interference elimination in high frequency neon signs has been the subject of investigations at the G.P.O., and, as a result, at least one type of high frequency neon now on the market (11) does not give rise to radio interference. Another difficulty was that high frequency discharge tubes do not exhibit a ready clean up of deleterious gases, as do the positive column discharge tubes operating at normal supply frequencies; this makes it more difficult to produce tubes of satisfactory colour capable of maintaining such colour for 2,000 to 3,000 hours This difficulty has apparently been overcome by Kingsley Lark, who has produced high frequency neon tubes in a variety of colours, including red-orange, blue, and green, in sizes from 5 mm. to 20-22 mm. diameter. An indoor high frequency sign installed by him at Victoria-street Station in 9-10 mm. red-orange, 11-12 mm. gold, and 15-16 mm. blue tubing, has been alight for 12 hours a day since December, 1935. It has been supposed that high frequency neon could be developed to give the same effect as high tension neon at a much lower energy consumption. This belief has been largely based on the results obtained by Foulke (12), who attained efficiencies of 4 candles/watt for electrodeless high frequency lamps containing mercury vapour with an addition of argon. The conditions in Foulke's experiments were, however, much more favourable than those existing in discharge tubes employed for sign and decoration purposes. While Foulke employed spherical bulbs, neon tubes for sign and decoration purposes have long tubular envelopes of relatively small diameter, so that the path to be ionised is much longer, while the chances of an electron losing its energy by collision with the walls of the vessel are much greater than in Foulke's lamps. The power consumption figures for high frequency neon, very kindly furnished by Kingsley Lark, are 4 to 5 watts per foot for 10-11 mm. tubing. Similar power consumption has been deduced by the author for 10-11 mm. high frequency neon developed by Warner and Adams, taking the rated energy consumption for their "writing neon," and making due allowance for the rate at which the tube fills with glow during the "on" part of the cycle and for the duration of the "off" part of the cycle. These figures are identical with those for high tension neon. The power factor of high frequency neon is markedly better than that of high tension neon, and, according to Kingsley Lark, may be as high as .6 to .7, but this advantage is less important than it would be in the case of true low-voltage neon, since it does not eliminate the necessity of precautions against radio interference or the need for auxiliary apparatus. High frequency neon appears to be giving valuable results as far as small interchangeable indoor signs and the extremely interesting "writing neon" are concerned, but even its advocates have been obliged to admit that there is no likelihood of it replacing the bulk of high-tension neon. The high frequency oscillator, the problem of insulation, and the problem of screening, introduce complications which are incompatible with the extreme simplicity of installation and maintenance which should be the keynote of low-voltage neon. The circumstance that various investigators have not been able to improve radically upon the results of Hayes-Gratze in 1923 is certainly discouraging, showing as it does that such improvement must be difficult if not impossible to achieve. An exception to the above general conclusion is the work of J. C. Wilson, which, quite unaccountably, has not been pursued by any other investigator, and which appears to indicate possibilities of animated shop window display neon much more attractive than the existing types.

Hot Cathode Tubes.

Positive column discharge tubes possessing hot cathodes of high electron emissivity, starting means and auxiliary means of ionisation in the region of the positive column, have been the subject of intense investigation for many years. The use of oxide electrodes heated by the discharge was suggested by Claude in 1910 (13) and an equipotential Wehnelt cathode comprising a performated metal pocket filled with electron emissive compounds such as lime was proposed by Donath in 1913 (14). Since then a large number of hot cathodes have been developed by numerous investigators and various types of such cathodes have been described in recent papers by Mailly (15), Buttolph (16), and J. W. Ryde (17). Various starting methods have been developed. Philips in 1919 (18) developed a method of starting in which an auxiliary discharge was initiated between a cathode and an auxiliary anode in its immediate vicinity, the auxiliary anode being connected externally to the main anode through a high resistance. At the same time Pintsch Akt. Ges. (19) developed a starting method utilising a metallic coating situated on the exterior of the discharge tube and connected to one of the main electrodes, as the plate of a condenser, and the gas in the positive column region as the other condenser plate, the glass envelope of the tube acting as the dielectric. More recently ionisation of the positive column region by means of high frequency current from a small tesla was introduced. The development of highly emissive cathodes and of adequate starting methods enabled the production of very efficient hot cathode discharge

tubes suitable for flood lighting (20). The positive column in flood lighting discharge tubes is under 3 ft. in length, the consumption is from 120 to 170 watts per ft. of positive column, the efficiency is from 12 lumens/watt for light blue or light green to 9.5 lumens/watt for red and 9 lumens/watt for dark green, and the uncorrected power factor is .3. These tubes are designed for A.C. circuits, 200 to 260 volts, have two preheated spiral electrodes, both adapted to act as highly emissive cathodes and energised from separate transformers, and a tesla coil for ionising the positive column region; such tubes may also have two auxiliary electrodes, one in the proximity of each main electrode. The above construction, however, does not lend itself to discharge tubes of the low voltage type suitable for sign or decoration purposes. The construction described, if applied to relatively long tubes of relatively small diameter, particularly if bent into complex shapes such as letters of the alphabet, etc., results in tube voltages which cannot be possibly classified as low. There were a number of attempts to overcome this difficulty, all attempts having the common feature of

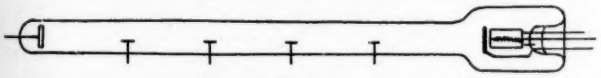

Fig. 1.

provision of a large number of auxiliary electrodes situated intermediate the main electrodes. Fig. 1 and 2 show the positive column tubes designed to work on low voltages; Fig. 1 shows a construction developed by B.T.H., while Fig. 2 shows a construction due to Abadie. The discharge tube shown in Fig. 1 has at one end an equipotential cathode

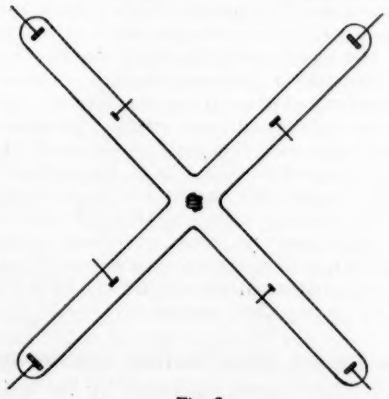

Fig. 2.

energised by an internal heater and an auxiliary electrode close to the cathode for initiating the discharge, and at the other end the main anode. Between the main anode and the cathode there is a large number of small auxiliary anodes connected to the main anode through high resistances elements. It may be noted that while this arrangement makes the starting voltage of the tube substantially identical with the running voltage, the voltage drop per unit length of the positive column must still remain high so that it is not possible to operate any considerable length of tube on ordinary household electric supply. The construction shown in Fig. 2 differs from that shown in Fig. 1 chiefly in that the cathode is not situated at one end of the discharge tube, but at an intermediate point so that, without increasing the distance between the cathode and the anode but employing several anodes, the total length of tube in a section which may be operated at a given voltage is greatly increased. This construction lends itself to the production of individual letters, each with its own chokes, the number of chokes per letter depending on the length and diameter of tubing. At present all tubes of this type include mercury vapour, and red-orange colour is unobtainable, but blue, green, yellow, mauve, and white tubes are manufactured. The chief drawback of this type of neon is the large number of carefully balanced chokes necessary. For example, a 2 ft.-high letter "X" has one cathode, four main anodes, and four auxiliary anodes, and therefore requires either eight chokes or four chokes and four resistances. It is now generally recognised that whatever the merits of the hot cathode positive column tube, it does not appear to promise an ideal solution as far as low voltage neon for sign and decoration purposes is concerned. The electrode drop has been so far reduced that further improvement in this respect would not materially reduce the tube voltage. The voltage drop in the positive column may be further reduced by means of a high frequency discharge, but this, in the limit, would convert the tube to a high frequency tube, already described in this paper. The voltage drop in the positive column may be reduced by a suitable combination of gases; thus a mixture of neon with an addition of about 1 per cent. of argon is much more readily ionisable than pure neon. There is, however, an objection to gas fillings incorporating small admixtures of gases in addition to the main filling, in that tubes with such fillings tend to fail more rapidly through decrease of conductivity than tubes with a single gas filling or a composite gas filling in which all ingredients are in large proportions.

Negative Glow Tubes.

The negative glow tubes are a more recent line of development. Negative glow lamps were developed in 1917-1918 in the Schenectady laboratories (21) of the General Electric Co., and simultaneously in Germany by Pintsch Akt. Ges. (22, 23). During 1919-1921 various negative glow lamps for display purposes were constructed by a number of independent investigators, notably by Skaupy and by Schmierer. These display lamps had envelopes similar in shape and size to ordinary incandescent lamp envelopes and had a pair of closely spaced electrodes, one or both electrodes being either so shaped, or so coated with an insulating film over parts of the surface, or so covered with an appropriately perforated stencil, that negative glow within the lamp appeared to assume the form of letters or designs. The most successful of these was the construction in which one or both electrodes were either of bent wire or stamped out of sheet metal,

being shaped into individual letters, words and simple outlines or silhouettes of objects (24, 25). These display lamps had very little success, partly because of the restricted size of the luminous display presented, partly because of their low luminous intensity. Until quite recently no attempt was made to adapt the negative glow discharge to tubes similar in appearance to ordinary high-tension neon. Attempts to achieve this result were made during the past few years by Heintz, by Rennerfelt, and by the author.

Heintz, in 1930 (26) constructed negative glow discharge tubes shown in Fig. 3, in which the discharge took place between two long straight wires, flexible but resilient, the wires being kept in a desired spaced

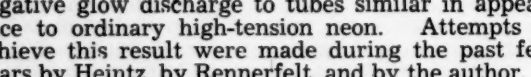

Fig. 3.

relationship and out of contact with the walls of the envelope by a large number of bead insulators. The beads were of hard glass or some similar material, each provided with two holes through which the wire electrodes passed. They were located at more or less equal short intervals along the wire length, and the wires were slightly flattened either side of the bead holes so that the beads were definitely located. The combined electrode and insulator structure was flexible in one plane but rigid in all other planes, and extended substantially the entire length of the envelope of the discharge tube. In this manner very long tubes could be constructed, and it was also possible to bend these tubes into various shapes provided the axis of the tube remained in one plane. Heintz's tubes could be operated at normal household supply A.C. or D.C. voltage, and could be constructed in a variety of colours. They had a number of disadvantages, however, which precluded their success. In the first place, the circumstance that tube bends had to be arranged so as to keep the tube axis in one plane was a drawback, in that even simple shapes like letter " A " could not be made up in a single section. Again, the cathode surface per unit tube length was very small and the luminosity of the tube was accordingly very low. Another very serious disadvantage was that, owing to the close fit of the wire electrodes in the holes of the insulating beads, the negative glow formed on any portion of the electrode could not spread over the entire electrode, as in the case of a continuous conductor, the sections of an electrode between consecutive insulator beads behaving as small independent electrodes in parallel. Since the voltage necessary to initiate the discharge tended to be greater than the voltage drop across the tube when the discharge was formed, the tendency was for the discharge to concentrate in one small region of the tube, where the discharge was first initiated, the rest of the tube remaining non-luminous. This tendency to " patchy " lighting could be counteracted to some extent by employing a gas filling such that there was little difference between the starting and the running voltage, but it was found that the precise conditions which enabled a substantially uniform luminous effect were extremely critical and, if produced, could not be retained for any reasonable time, i.e., were not consistent with a practicable working life of the tube.

Simultaneously, but independently, Rennerfelt (27) tackled the problem on somewhat different lines. The construction he adopted was, with the exception of one feature, similar to that proposed earlier by Chapman, of whose work he was apparently unaware. Like Chapman, he employed two spiral electrodes extending the length of the elongated tubular envelope, and, like Chapman, he chose a construction in which the spiral electrodes were co-axial. The novel feature in Rennerfelt's construction was the use of two spirals of the same diameter, co-axial and with the turns interlaced and spaced so that actual contact was avoided. A typical construction is shown in Fig. 4. Apparently Rennerfelt did not attach much importance to the problem of separating insulators. In some instances he apparently employed insulators of the type used in earlier discharge tubes by other investigators; in other cases he dispensed with insulators

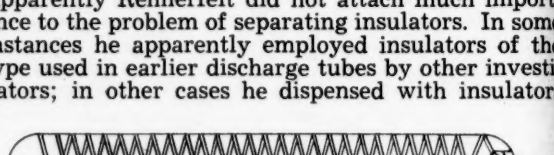

Fig. 4.

entirely, relying on the friction between the spirals and the envelope with which they were in contact to keep the structure in a correct position. This construction had three important advantages over Heintz's tubes; there was no need to restrict tube bends so as to keep the tube axis in one plane, there was no impediment to the spread of the negative glow over the entire cathode surface, there was a much greater cathode surface area per unit length of discharge tube, and consequently greater luminosity. The disadvantages of Rennerfelt's construction were, first, that he did not provide any adequate means enabling his electrode structure to be drawn into envelopes bent in a complex manner, without distortion or shorting of the spiral electrodes, and second, that his construction did not enable the attainment of really high luminosity except in the case of tubes of very small diameter. As will be shown later, to attain high luminosity for red-orange it would be necessary to employ tubes of about 5 mm. diameter, and high luminosity in blue, green, or other colours involving the use of mercury vapour could be attained only with such small tube diameters that the results would be of no practical interest.

Some Recent Experimental Developments.

Negative glow tubes developed by the author have been briefly described in a recent article (2). He employed a number of different constructions, those

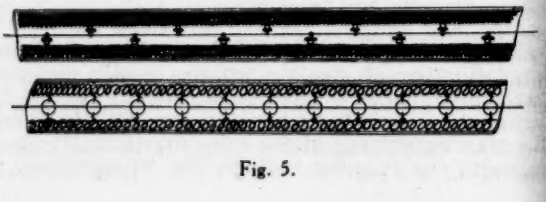

Fig. 5.

used in the majority of his experiments being shown in Fig. 5. In all cases flexible electrodes, extending substantially over the entire length of the tubular envelope, were employed. The electrodes were kept in a desired spaced relationship by a large number of insulators mounted on a common flexible support, the entire structure being very flexible in all planes. In the majority of the experiments spiral electrodes of soft iron wire, pyrex insulators and a soft molybdenum wire as a common flexible insulator support were employed. The pyrex insulators were fused to the molybdenum wire support and were attached to the spiral electrodes, by means of small molybdenum hooks fused into the pyrex and hooked on the electrodes. An essential feature of construction was that the combined electrode and insulator structure could be drawn into a long tubular envelope bent into a complex shape by a pull applied to the common flexible insulator support, without the electrodes becoming distorted in the process. These constructions had a number of advantages over those due to Rennerfelt and to Heintz. In the first place there was no restriction as to the manner in which the tubular envelope of the discharge tube might be bent; there was not in any circumstance any danger of shorting or deformation of the electrodes, nor was there any necessity to limit the bends so as to keep the tube axis in one plane. Secondly, there was no impediment to the spread of the negative glow over the cathode surface as in the construction adopted by Heintz. Thirdly, there was no restriction as to the extent of the cathode surface per unit tube length, as in the case of Heintz, nor any necessity to employ spiral electrodes of the same diameter as the glass envelope, as in the case of Rennerfelt; there was on the contrary a very considerable latitude in the matter of electrode shape and dimensions which accordingly could be chosen to give the best results from point of view of luminosity, consumption and life. Experiments were conducted with rare gases such as neon, helium and argon, and also with mercury vapour used in combination with rare gases. Ultimately pure neon was adopted for red-orange and mercury in combination with argon for other colours. It was found that while the spectrum, as might be expected, was identical with the positive column spectrum as far as wavelength was concerned, the energy distribution was different. As a result neon gave a more orange light than in the case of positive column tubes, while mercury argon was a paler blue than in the case of high tension neon. To obtain a satisfactory blue, the author found it desirable to employ a blue "daylight" glass envelope. Other colours, such as green and white, were obtained by means of a mercury argon discharge in fluorescent Fischer glass tubing. It was soon discovered that by employing spiral electrodes and an appropriate gas pressure, light intensities much higher than those previously obtained with cold electrode negative glow discharge lamps could be produced. The maximum effect was obtained when the spiral diameter and the gas pressure were such that the negative glow was entirely confined to the interior of the spiral functioning as the cathode, since under these conditions the number of electrons striking the glass wall was negligible. It was found, furthermore, that for maximum effect the spiral diameter and the gas pressure had to be such that the negative glow completely filled the spiral electrode interior. The choice of gas pressure was governed by a number of considerations. The thickness of the negative glow decreases and its intrinsic brilliancy increases with increase of pressure. The thickness of the cathode dark space is inversely proportional to pressure, as is also cathode disintegration. On the other hand increase of pressure increases heat loss and current density at the cathode corresponding to the normal cathode fall of potential increases with pressure. Increased pressure is a safeguard against premature failure due to gas absorption, but this factor is less important than in the case of high tension neon, since absorption in these low voltage tubes is remarkably low. The most satisfactory pressures for iron spiral electrodes were experimentally established for pure neon and for argon in addition to mercury vapour and measured on an Apiezon "A" oil gauge. The corresponding optimum spiral diameters were found to be 3.7 mm. mean diameter for neon and 1.1 mm. mean diameter for argon-mercury filling. These figures show clearly why high luminosity could not be obtained with Rennerfelt construction in which the spiral diameter must be substantially equal to the internal diameter of the glass envelope. Tubes constructed in the above manner operated readily, as might be expected, both on A.C. and on D.C. circuits, though on D.C. only one electrode, of course, exhibited a negative glow. The majority of experiments were made with 15-16 mm. tubing on 230-volt. 50-cycle supply. Spiral electrodes 3.7 mm. diameter were used for neon, and electrodes, each consisting of three 1.1 mm. diameter spirals, were used for argon-mercury filling. The normal operating condition of a tube was defined as the condition corresponding to a current at which the electrodes were just full of glow, that is, a maximum current consistent with the normal cathode fall of potential. Tube voltage was independent of tube length, and at normal loading on A.C. was about 190 volts. Contrary to expectation tube current was not quite proportional to tube length, the consumption per ft. being somewhat less for longer tubes. Tube watts. were dependent on spiral pitch as well as on the precise gas filling, and tubes were constructed with a consumption of from 7.5 watts per ft. for 15-16 mm. 6 ft. long tubes up to 10 watts per ft. for 15-16 mm. tubes of short length, these figures not including the losses in the current limiting means in series with the tube. Current limiting means usually employed were under-run metal filament lamps or vitreous enamelled fixed resistance units. The use of a small iron core choke as a current lighting means would involve very little wattage loss, so that the above consumption figures may be taken as indicative of tube consumption on A.C. circuits not exceeding 250 volts. It was found that the volt ampere characteristic became slightly positive when normal loading was exceeded, so that consideration of stability did not make it imperative to absorb a large fraction of the supply voltage in a current-

limiting device; in fact, in several experiments a neon-filled tube was operated direct on 230 volts without any current-limiting means in series. The results of a test on a typical neon-filled 15-16 mm. tube 3.5 ft. long and bent into the shape of a letter "A," conducted by Faraday House, are given in Table I. It will be noted that while the consumption of this particular tube was 9.7 watts per ft., the candle-power per ft. was very low. As might be expected, the luminous effect at close quarters was accordingly much softer than in the case of high-tension neon. The appearance at a distance, however, was quite different from what one might anticipate on the basis of candle-power measurements. At a distance of 100 ft. the visual impression was very little different from that produced by an adjacent high-tension neon tube of standard manufacture. This very interesting phenomenon of apparent increase of brilliancy with distance was observed in all tubes of similar construction irrespective of colour, shape, and size. The reason for this is by no means obvious; the author would, however, tentatively offer the following explanation. The tubes in nearly all cases were in opal glass to hide the spiral electrodes, although the appearance of blue and green tubes in clear glass was not displeasing. In all circumstances, however, the luminosity of the tube was not absolutely uniformly distributed over the surface. While in the clear tubes the electrodes were visible at close quarters, in the case of opal tubes there was a kind of fine network of more or less bright lines, due to electrode shadows, not sufficiently pronounced to obtrude on the observer's notice, but unquestionably present. At close quarters the eye experienced a sensation due to the average effect of the brighter and duller portions of the tube surface, this sensation being in conformity with the low candle-power per ft. of the tubes. At an increasing distance, however, the observer would not be able to distinguish the duller regions so readily, and would, at a sufficiently great distance, be conscious only of the brighter portions, this giving an illusion of a much brighter surface. According to this theory, the luminosity of the tube as estimated by the observer should increase hyperbolically with distance of the observer from the light source, which appears to be in accord with the observations. From a practical point of view the apparent variation of luminosity with distance is an important advantage over the constant effect observed with the usual high-tension neon. The tubes exhibited a consistency of behaviour which was confirmed by a Faraday House test on five tubes 15-16 mm. diameter bent into letters of the alphabet, the results of this test being given in Table II. The average deviation of the readings from the mean values was about 5 per cent., which, in view of the difficulty of estimating precisely the point at which a tube was just full of glow, was regarded as satisfactory. To test the life of the tubes, three neon-filled tubes, 15-16 mm. diameter and 2 ft. long, bent into horseshoe shape, were submitted to Faraday House. These tubes had precisely the same gas filling and electrodes as the tube whose performance is given in Table I. The results of the life test are given in Table III. It will be noticed that the watts per ft. are nearly double the value given in Table I. Ignoring the premature failure of the first tube, which was obviously defective, the results show that the tubes at a loading nearly double that defined as normal by the test results given in Table I were intact at the end of 1,000 hours, and that any hardening effect present was not sufficient to manifest itself in the tube consumption at the end of that period. The candle-power, however, was down at the end of the test to about one-third the original value. Such a drop in candle-power in the case of a lamp would indicate that it had long passed its useful life. In the case of tubes for sign and decorative purposes, however, we are concerned, as stated earlier in the paper, not with candle-power, but with visual sensation which is proportional to the logarithm of the candle-power. Furthermore, the magnitude of diminution of visual sensation is estimated by eye which is not adapted to measure differences. It would be expected, therefore, in view of these theoretical considerations, that the tubes would still retain a serviceable appearance at the end of the 1,000 hours, a view which appears to be in agreement with the actual appearance of the tubes at the termination of the life test. It may reasonably be expected, therefore, that if the tubes were operated at the same loading as letter "A," referred to in Table I, these tubes would be serviceable at the end of 2,000 hours, assuming that cathode disintegration is directly proportional to coulombs passing through the tube. Actually, cathode disintegration is proportional to coulombs only in the case of pure, completely gas-freed metallic surfaces. According to J. J. Thomson (28) disintegration in the case of cathodes whose surface is covered with a trapped film of gas is proportional to the product of coulombs and the difference between the bombarding voltage and the normal cathode fall of potential for the particular gas. For this reason oxidised iron electrodes disintegrate very little so long as the cathode fall of potential is normal, a circumstance full advantage of which is taken in the construction of high-tension neon tubes, in which the electrodes of oxidised iron are now employed instead of iron electrodes with clean, outgassed surfaces. Assuming, as a conservative estimate, that disintegration of an oxidised iron cathode per coulomb at normal cathode fall of potential is 40 per cent. of the disintegration per coulomb for the electrode when the tube is subjected to double its normal loading, it follows that these tubes, operated under conditions given in Table I, should still be serviceable after 5,000 hours. To determine the power factor of the tubes, two tubes were tested at Faraday House. These tubes were identical with those referred to in Tables I and III, except that the spiral pitch was somewhat closer and the watts per ft. of the tube accordingly somewhat higher at normal load than in Table I. From the results given in Table IV, it follows that the uncorrected overall power factor of a tube in combination with a current limiting series resistance is about 0.9. The

power factor does not sensibly change with load so long as normal load is not exceeded, since a reduction of load is merely equivalent to reduction of tube length operating at normal load. As the measurements in Table IV. were made with instruments whose readings were independent of frequency, it may be concluded that these tubes did not generate appreciable high frequency current harmonics. Another test which appears of interest was a comparison of the behaviour of a tube on A.C. and on D.C. The results of the test performed at Faraday House on a 15-16 mm. diameter opal glass neon filled tube are given in Table V. It is interesting to note that the tube appeared full of glow both on A.C. when both electrodes functioned as cathodes and on D.C. when only one electrode was associated with the negative glow. The circumstance that tube voltage was higher on D.C. than on A.C. is easily explained by the variation of A.C. voltage during a cycle and the fact that a certain voltage value must be reached before a discharge can be formed and another value before it extinguishes. The circumstance that the ratio of D.C. volt amperes to A.C. volt amperes is less than the power factor cannot be accounted for so readily, but may, perhaps, be explained by the fact that the A.C. discharge covers less than the full cathode region for a certain time interval after its formation, and for a certain other time interval prior to its extinction during a half cycle. Owing to the fact that, as shown in Table III, hardening in these tubes is not as marked as in high tension neon, it has been possible to construct tubes exhibiting novel luminous effects by adding impurities to the gas filling or by employing gas pressures lower than those commonly employed in high tension neon. In this manner tubes giving a flickering red-orange discharge on A.C., and A.C. tubes giving a flickering mauve light, were constructed. The types of flicker in these tubes are pleasing and different in appearance from anything previously obtained with high tension neon. It was also observed that by varying the value of the current limiting resistance in series with a tube it was possible to cause the glow to extend or contract over the tube length in a manner similar to that observed in high frequency "writing neon," an effect of obvious practical utility.

Future Possibilities.

It appears to the author that the tubes constructed by him, while not in their final state of development, nevertheless constitute the nearest approach to the solution of the low voltage neon problem. Undoubtedly there is room for a good deal of further experimentation and improvement. Thus, for example, it would be desirable to produce tubes capable of operating at 100-120 volts. So far no such tubes have been constructed, but there seems little doubt that the result could be achieved by employing electrode materials of higher electron emissivity than iron and suitable gas fillings, such, for example, as neon with an addition of .5 per cent. to 1 per cent. of argon. Again, it might be considered desirable to increase luminosity, although the author does not feel such increase would be advantageous for reasons already stated in this paper. There is every reason to believe that such increased luminosity could be obtained without difficulty by employing electrodes of higher electron emissivity than iron; for example, electrodes coated with compounds of barium or barium and strontium. This belief is supported by certain experiments carried out by the author about 1920, when he obtained an intense negative glow employing an incandescent tungsten wire cathode and a cold tungsten anode in an atmosphere of neon and helium, as may be seen from the photographic plate in his possession. The belief is further strengthened by the work of Lederer (29), and of the Westinghouse Lamp Company (30). Both efficiency and life could be doubtless improved. Finally, the shadow effect of the electrodes on the opal glass envelopes could be eliminated by inserting light wire support struts into the glass insulator beads or other glass beads attached to the electrode assembly, the struts serving to keep the electrodes adequately spaced from the glass wall. This last feature, however, would, in the author's opinion, be a mistake, since it would eliminate the present effect of apparent increase of brightness with distance, which, as already explained, has important advantages.

APPENDIX.

TABLE I.

Horizontal Candle Power.	Tube Volts.	Tube Watts.
2.7	186	34.0

Neon tube operated on a 240-volt. 50-cycle A.C. circuit, with a 240-volt. 100-watt gas-filled lamp in series as a current limiting resistance. After initial test the tube was placed out of doors and run for eight hours per day for two days. During this time the weather varied from mild to rather cold and cold sleet fell for some time on the second day. At the end of this period the tube was intact and did not appear to have suffered any damage.

TABLE II.

Test No.	1		2		3		4	
Tube.	Amp.	Volt.	Amp.	Volt.	Amp.	Volt.	Amp.	Volt.
N	.235	176	.240	176	.245	175	.260	175
S	.091	173	.091	174	.090	174	.092	171
O	.175	168	.145	167	.150	167	.180	170
R	.155	175	.165	175	.157	175	.175	172
E	.177	172	.180	175	.155	175	.155	173

Each tube was tested on a 230-volt. 50-cycle supply with a variable current limiting resistance in series, the variable resistance being adjusted until the tube was estimated to be full of glow. Each tube was run for about five minutes, and current consumption and voltage across the tube measured. The tube was

then switched off, allowed to cool down for half an hour, and the readings were then repeated. This operation was repeated four times.

TABLE III.

Hours.	Tube No. 1646. Watts.	C.P.	Tube No. 1647. Watts.	C.P.	Tube No. 1648. Watts.	C.P.
0	35.0	3.0	35.3	3.2	35.1	3.1
200	Failed		35.0	—	34.9	—
400	after		34.6	—	34.5	—
600	4.5 hrs.		34.6	—	34.6	—
800			35.0	—	34.9	—
1000			34.8	.9	34.7	1.0
			Tube still intact.		Tube still intact.	

Tubes were measured and run on 230-volt. 50-cycle supply, each tube being operated in series with a 240-volt. 100-watt gas-filled lamp as a current limiting resistance. The candle-power measurements were broadside, and were taken for each tube initially and at the end of 1,000 hours.

TABLE IV.

Tube.	Current Amps. 1	2	Tube Watts. 1	2	Voltage across Tube. 1	2	Series Resistance Ohms. 1	2
A	.158	.157	23.7	23.4	191	190	302	302
E	.170	.165	27.0	27.0	190	191	285	285

Two tubes were tested on a 230-volt. 50-cycle circuit, each with a current limiting resistance in series. The resistance was in each case adjusted until the tube was just full of glow. Readings were taken on correct adjustment of resistance, the tube was run for four hours, and the readings were then repeated.

TABLE V.

Test Circuit.	1 Amps.	1 Volts,	2 Amps.	2 Volts.	3 Amps.	3 Volts,
230-volt. 50-cycle A.C.	.073	161	.083	163	.078	163
220-volt D.C.	.041	190	.042	192	.041	191

Tube was tested on a 230-volt. 50-cycle A.C. circuit and a 220-volt. D.C. circuit, a resistance being used in series with the tube in each case. The tube was tested for current consumption and voltage across the tube, the resistance being adjusted until the tube was estimated to be just full of glow. The tube was switched off and allowed to cool. The same measurement was again taken twice in the same way, on each circuit.

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DISCUSSION

Captain C. HIGGINS commented with satisfaction upon the fact that since his company had introduced its new range of high intensity fluorescent tubes in various colours the extent of the adoption of those colours in preference to the ordinary orange red had been very marked. His company were making rather more than 60 per cent. of their signs in colours other than red.

For window signs high intensities were not wanted and were not desirable, but neon tubes could give quite good efficiency in windows. For outside signs, high intensity or brightness was demanded; for that purpose the neon units must give high lumens per watt and must be in vivid colours. By a proper combination of the colours available, and high intensity, signs could be produced which were not only attractive in themselves, but which would give a floodlighting effect to the buildings which was also very attractive.

Users would not be satisfied with the suggested life of 3,000 hours for neon lighting units. His company had to guarantee that tubes would burn continuously for six months, and expected them to do so always. Tradesmen using neon signs for windows expected the units to last considerably longer than that, and, in fact, they did last considerably longer although the company did not guarantee it.

The standardisation of neon signs (as distinct from the standardisation of inherent parts of the signs) was undesirable, for presumably the object

of a sign was to advertise, and each advertiser wanted something distinctive; for that reason they adopted many different arrangements and types of printing matter in their ordinary advertisements. In the best modern practice, however, the inherent parts of signs were standardised; for example, an ordinary fitter could change the glass of a letter quite easily by pulling it out of its socket and replacing it by another.

The cost of power factor correction was about 3 per cent. of the cost of the sign. Perhaps one of the reasons why high frequency current signs had died out was the fear of receiving shocks from them; even though the voltage might not be sufficient to prove fatal, a shock might cause a man to fall off a ladder, and if a man were killed there was not much satisfaction in proving that his death was due to the fall rather than to the shock!

In a reference to hot cathode tubes, Captain Higgins suggested that their brightness, which was of the order of 100 c.p. per foot run, was too great for ordinary sign use; it was not possible to read a large letter at a distance of more than 100 yards owing to the intense halation due to the brightness.

Dr. J. W. T. Walsh said that he could not follow the author's reasoning that, because of the Weber-Fechner law, neon tubes should be rated on a logarithmic scale. Surely the same argument would apply equally to ordinary lamps used for general lighting purposes, and it had never been proposed to rate these on a logarithmic basis; in fact, it seemed far better not to attempt to rate light sources on a scale of sensation, but to retain the existing physical basis for the purpose.

With regard to the statement that the low-voltage neon tubes gave a soft luminous effect when viewed from close quarters, whereas at a distance they took on an added brightness and appeared to be of about the same brightness as high-tension lamps, Dr. Walsh said that if that effect could be established experimentally, it was a matter worthy of thorough investigation, for there was no obvious reason for such an effect on our present knowledge of the manner in which the eye functioned.

Mr. J. N. Bowtell, in discussing the problem of obtaining a normal cathode fall, said it was well known that, with two parallel plates in a discharge tube, if these plates had been vacuum treated extremely carefully, it was extraordinarily difficult to obtain normal cathode fall conditions over the entire surface of the plates. There was always a tendency to form small localised bright spots of higher current density; these spots gave rise to heavy sputtering of the material of the plate, with consequent blackening of the tube. It appeared that this would occur in the negative glow tubes described in the paper, causing a serious shortening of the useful life of the tube. This seemed to be borne out by the figures given in Table III showing that the candle-power of two tubes had fallen by more than two-thirds in a thousand hours.

With regard to the question of high tension, he said that in the majority of neon sign installations the voltage was not as high as 10,000, a figure mentioned by the author. The maximum voltage to earth was usually of the order of 3,000, and only exceeded this figure in a few specialised installations.

Professor J. T. MacGregor Morris, discussing the author's reference to flickering tubes and the statement that by varying the value of the current limiting resistance in series with a tube, it was possible to cause the glow to extend or contract over the tube length in a manner similar to that observed in high-frequency "writing neon," asked whether the glow extended from the supply end as the current was increased; it seemed quite natural that that should be so if the two electrodes were the same distance apart throughout the length of the tube, for such extensions would be in accordance with the law that the electrical circuit tries to become as big as possible, provided the glow increased from the *supply* end of the tube.

Another matter to which Professor MacGregor Morris referred was that of terminology, particularly the rather wide application of the term "luminosity." He pointed out that the purpose of an advertising sign was to arrest attention; that could be done in a number of ways, such as by starting and stopping the light, by having the light really intense, or by providing a background, illuminated or otherwise. All those effects apparently came within the term "luminosity," as used by the author, and he suggested that that term might be replaced by others, such as "attractivity," "vividity," "advertivity," or "shockivity"!

Added.—Since speaking, Mr. Beutell has drawn my attention to the fact that the term "conspicuity" is being considered as another alternative, and, in my opinion, is the best term yet suggested.

Mr. C. A. Morton suggested that the title of the paper did not correctly represent the nature of the paper, and might be modified with advantage.

Mr. B. N. Clack expressed surprise that the author had described one American form of ultra-violet lamp as a negative glow lamp. Inasmuch as it operated with a metal filament lamp in series, he had always regarded it as being a true arc; that was substantiated by the fact that the operating voltage across it was only a few tens of volts.

A possible explanation of the difference in luminosity as between low-voltage and high-voltage tubes from a distance was the colour difference, due to the different conditions of excitation in the two cases.

Mr. D. C. Mandeville demonstrated the point made in the paper that the luminosity of the low tension neon tubes relative to the high tension tubes appeared to increase when viewed from a distance. He illuminated a low-tension and a high-tension tube, and, at his suggestion, the members present at the

meeting inspected them at close quarters and then from the back of the hall. The difference between the luminosity of the high-tension and the lecturer's low-tension tubes, viewed from the back of the hall, was hardly appreciable, whereas, from close quarters, the high-tension tube appeared much the brighter.

Mr. F. P. BENTHAM criticised the design of the neon lighting displays in London from the artistic application standpoint, not as regards the actual design of the apparatus. Inasmuch as the illuminating engineers seemed to have sole rights in our cities after dark, he urged that it was their duty to produce really artistic and attractive displays.

Prior to the meeting, he had inspected the neon lighting displays at Leicester-square, Piccadilly-circus, Haymarket, Trafalgar-square, and the Strand, and had seen only one display which was pleasing artistically, particularly from the point of view of colour.

He admitted that the design of displays in such a new material was a very difficult problem, especially as advertising was usually involved. But there was no excuse in a display for the colour of one tube to clash with another. Developments had placed a good range of colours at the disposal of the designer. However, even in the most recent installations, a beautiful blue-green would be used side by side with the crude standard red, which was the colour of 80 per cent. of the neon tubes used.

Such an inspection as he had made before the meeting would be of value to all designers, and there could be no difficulty in recognising the display referred to. Although quite small, it was in two beautiful colours, and by its artistic appearance drew more attention to itself than an installation many times the size and brightness on a neighbouring building.

Mr. G. H. WILSON expressed the view that neon sign designers were not paying sufficient attention to the brightness of the tubes they used. Clearly, he said, it was desirable that the efficiency of the tubes should be increased as far as possible. Especially when used for interior or exterior lighting rather than sign work, one must expect increases in the brightness of the tubes, and one might be forced into reducing the effective brightness by putting the tubes into fittings. But there seemed to be a tendency to install tubes for sign work without considering the size and brightness relative to the brightness of the background, with the result that the tubes had not the maximum clarity. For example, in a sign near his home the tubes were so bright relative to a practically black background that it was almost impossible to distinguish them from quite a short distance, due to their radiation from the letters. It would seem to be wise, after a sign was installed, to adjust the current in order to give maximum clarity to the letters.

Mr. W. J. RICKETS, referring to low voltage tubes of the kind demonstrated by the author of the paper, remarked that the increased safety associated with the use of low voltages was very important. This should tend to the wide use of such tubes for shop window displays and in like situations to which the public or untrained persons may have access.

In regard to the apparent luminosity of the author's low voltage tubes, he had observed these up to a distance of the order of 200 feet, when situated alongside high voltage tubes. At close quarters the brightness of the high voltage tube appeared considerably the greater, but on observation at increasing distances the brightness of the low voltage tubes appeared to increase relatively, at first rapidly and then more slowly, so that at a distance the contrast in brightness between the high voltage tube and the author's low voltage tubes was not marked.

Mr. A. R. RANGABE pointed out that the blue colour low voltage tubes did not attain their full intensity for a considerable time, even in the comparatively warm atmosphere of the meeting room. He suggested that in the open on a really cold day the tubes would need longer time to warm up sufficiently to give a good colour.

Mr. J. S. Dow said he assumed that the intention was to use the neon tubes to produce a bright luminous display to be viewed from a distance, and not for the purpose of illuminating rooms. Judging from Table I in the Appendix, the consumption appeared to be about 12 watts per candle power, so that the candle power per watt obtainable from the tubes was rather low for the purpose of ordinary illumination. No doubt the brightness of neon signs was far greater than was necessary in many cases, and their effectiveness would be almost as great, even if the brightness of the tubes was very much less. Therefore, if with less brightness one could secure compensating advantages when working at low voltage, that might be worth while.

Mr. Dow concurred with Dr. Walsh that there seemed no reason why, as one viewed an object of varying brightness from a greater distance, the eye should pick out the brightest parts. Indeed, experience seemed to be quite the opposite to that. For instance, the individual fibres of an incandescent mantle could be observed at close quarters, whereas at a distance the mantle appeared to be just a mass. Again, the bulb of a pearl lamp when viewed at close quarters, appeared to have local bright spots, whereas from a distance the effect was substantially uniform.

He would rather attribute the effect mentioned to two other factors. In the first place, when viewing an object from a distance it was necessary to increase the brightness enormously in order to effect any material difference in its "conspicuity." In the second place as one receded farther away from coloured objects so that their image was received on the central part of the retina, the eye became more sensive to the red than to other colours. As one receded farther away from a red and green object, for example, the red tended to become brighter relative to the green. Hence a red sign in a window would

tend to "stand out" much more clearly when viewed from a position across the road than when seen from a position only a few feet away from the sign.

(Mr. H. Stafford Hatfield, in a written contribution, commented very favourably on the low-voltage neon tubes, and regretted that they were not yet manufactured commercially.)

Mr. P. Freedman, in reply, said that he understood the satisfaction expressed by Captain Higgins at the deserved success of fluorescent tubes manufactured by his company. No doubt the company materially assisted this success by wisely taking cognisance of the popularity of red-orange colour and in offering the public a number of analagous colours in fluorescent tubes, such as flame colour and rose-red. Fluorescent tubes of various colours in Fischer glass were manufactured by other companies in large quantities. The advent of fluorescent tubes, however, had not markedly affected the public demand for red-orange, which now constituted 80 per cent. of all installations.

He was glad Captain Higgins condemned the high intensity neon signs now employed in shop windows. He had endeavoured in his paper to define the requirements of a shop window display and to indicate how such requirements could be met. He could not accept Captain Higgins's contention that outdoor signs must give high lumens per watt. Outdoor signs now employed were most inefficient as light sources, although pleasing as signs; their overall efficiency, including the transformer, was 2 to 2.5 lumens per watt for red, 1 lumen per watt for blue, and 0.5 lumens per watt for green, for non-fluorescent tubes, and 2 to 2.5 lumens per watt for red, 1.75 lumens per watt for blue, and 2 to 2.5 lumens per watt for green, for fluorescent tubes. He was indebted to Dr. Schallreuter for these figures.

With regard to Captain Higgins's remarks concerning tube life, he would point out that customers did not run their tubes twenty-four hours a day, seven days a week. Mr. Mandeville recently observed that on a weekday, between 7 and 8 a.m., in the whole of Oxford-street, Bond-street, Regent-street, Piccadilly-circus, Haymarket, Coventry-street, Leicester-square, and Charing Cross-road, there were only thirty-six signs alight, these including fourteen small hanging and shop-window signs, a railway station, and all-night garage, two restaurants already open, an all-night chemist, and only one large neon display. In practice the customers, during the six months covered by Captain Higgins's guarantee, would not use their tubes even for 3,000 hours.

He could not agree with Captain Higgins that the ability of a fitter to replace a defective part was sufficient proof of standardisation; if this were so, then the Schneider Trophy aeroplane was a standard machine. In his opinion high tension neon was incapable of standardisation. He did not think that the artistic argument could be used against standardisation possible with low voltage neon. He fully agreed with Mr. Bentham that the present neon displays were not wonderfully artistic; they mostly consisted of block, Roman, or script letters and some unimaginative borders. The fact that standardised production could give artistic results has been proved by Swedish glass.

He concurred with Dr. Walsh that light sources should be rated in candle-power, or in lumens. His point was that discharge tubes employed as signs or decorations could not be regarded as light-sources, because they were not employed for illumination purposes. He was glad to find that this view was shared by Professor MacGregor Morris and by Mr. Dow. Such tubes should be rated on a basis consistent with their function, and it appeared to him that the logarithmic scale suggested by him fulfilled this condition.

He agreed with Dr. Walsh that the apparent increase of brightness with distance of his low voltage neon tubes constituted a phenomenon which had not been previously observed. This phenomenon was not confined to his low voltage neon but was also observable with certain other luminous bodies. He had demonstrated this to a number of independent observers and during this lecture Mr. Mandeville demonstrated the effect both with low voltage neon tubes and with high tension neon tubes with corrugated envelopes. There was no doubt as to the reality of the phenomenon. It was not the Purkinje effect, as suggested by Mr. Dow and Mr. Clack, since it could be observed upon comparison of luminous bodies of similar colour, and he did not think it could be explained on the basis of Mr. Dow's "Conspicuity" theory, since, in the case of two ordinary high tension neon tubes of similar colour but unequal brightness, the difference in brightness did not tend to disappear with distance in the same manner.

He confessed some surprise at Mr. Bowtell's argument regarding tube life. In the first place, it was pointed out in the paper that clean outgassed metallic surfaces were unsuitable because they disintegrated very readily. Secondly, the electrodes in the low voltage neon tubes in question were of iron wire not exceeding 0.3mm. in diameter. If localised heavy disintegration described by Mr. Bowtell was unavoidable, such electrodes would not last 100 hours at normal load. Finally, as stated in the paper, Table 3 corresponded to a life test at approximately double the normal load, i.e., under conditions deliberately chosen to produce cathode disintegration. The corresponding tube life at normal load, as pointed out in the paper, would be about 5,000 hours.

With regard to Mr. Bowtell's remarks concerning high tension neon installation voltages, 3,000 volts to earth obtains in installations with earthed mid-point of the transformer secondary when running voltage is 6,000 volts, but in such cases, to obtain starting, the transformer must give 10,000 volts unloaded, the figure given in the paper.

In reply to Professor MacGregor Morris he would point out that the term "luminosity" as employed in his paper did not embrace such effects as flicker, or

starting and stopping the light, but only the effect which appeared to be the dominant factor and which he suggested could be expressed quantitatively as a logarithm of candle power. He fully agreed with Professor MacGregor Morris that the attraction value of a sign was dependent on a number of factors, but it seemed to him that "attractivity" or "conspicuity" which would include all these factors was not capable of quantitative expression.

With regard to Professor MacGregor Morris's remarks concerning the "writing neon," these described precisely the behaviour of the low voltage writing neon which has been demonstrated in the course of this lecture.

In reply to Mr. Morton, from the academic point of view it might have been preferable to alter the title to "Development of Metallic Vapour and Gaseous Discharge Tubes for Sign and Decoration Purposes, Designed to Operate at Normal Household Supply Voltages"; he felt, however, that such a title would be too cumbersome.

The lamp mentioned by Mr. Clack was produced by the Westinghouse Lamp Company, who described it as a low current glow discharge lamp.

He could not answer Mr. Rangabe's remarks precisely as these tubes were not in commercial production, but even if blue tubes took a quarter of an hour to reach a steady running state, as is the case with mercury vapour street lighting lamps, he did not think this would be an important factor, as signs were switched on before dusk and operated continuously for many hours.

His explanation of the phenomenon of apparent increase of brightness with distance observed in his low voltage neon tubes was purely tentative; nevertheless, it appeared to him that it has not been shown to be untenable. He suggested that Mr. Dow's examples of the incandescent mantle and the pearl lamp were not analagous cases; a true analogy would be a comparison of two similar incandescent mantles, one of which had situated within it a smaller incandescent mantle so placed that the fibres of the inner mantle could be seen through the spaces between the fibres of the outer mantle. He believed that if such a test were carried out the single and the double mantle would appear equally bright at a distance but the double mantle would appear much brighter at close quarters.

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